THERMO-PHYSICS CORPORATION

INSTRUCTION MANUAL

GUARDED HOT-PLATE THERMAL

CONDUCTIVITY INSTRUMENT

MODEL GP-500

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1.0 DESCRIPTION OF INSTRUMENT

The Thermo-Physics Model GP-500 Guarded Hot-Plate is a rather complex scientific instrument designed and constructed to obtain highly accurate thermal conductivity data. Although the instrument is fairly simple to operate, it requires a thorough understanding of its principles and the operating procedures described in this manual. Careless sample installation and operation reduces the probability of obtaining good data, as well as exposing the instrument to possible damage. In order to perform measurements of maximum accuracy it will require some experience both in installing samples and balancing thermal controls.

In principle, the guarded hot plate consists of a flat main and guard heater assembly with identical flat samples placed on both sides and further enclosed by two flat fluid cooled heat sinks. An equal heat flux is produced axially in each sample by supplying electrical power to the main heater while the gradient through the samples is maintained by removing the heat with the heat sinks. The guard heater surrounds the main heater section of the main heater assembly and serves to establish an adiabatic plane at the main-guard heater interface extending into the sample to the heat sink surface. If the interface is truly adiabatic, then the assumption of unidirectional (axial) heat flow within the samples is valid. The ASTM C-177 Specification calls for a ratio of guard heater width to sample thickness to be at least 1.5 in order to insure that the adiabatic extends through the sample to the heat sink. The GP-500 has a 4" dia. main heater with a 7" O.O. guard providing a 1.5" wide guard. This permits a sample of 1" thickness to be tested within the ASTM Specification.

Facing the front of the GP-500, the test section is located in the left half of the modular cabinet. The test section proper is mounted on an aluminum base plate. The lower heat sink rests on a plexiglass insulator and is fastened to the base plate. Extending upwards from the base plate are 3 equally spaced threaded rods. These serve to support the upper heat sink, and are very useful if compressible samples are to be tested. If most samples are solid and can support the stack components, these rods may be removed, however the threaded holes in the base plate should be plugged using screws from beneath the base plate to prevent the stack insulation from leaking through. The height of these rods may be adjusted by screwing them further through the base plate, to accommodate various stack heights. These rods may also be used to apply pressure to the stack, to flatten slightly bowed samples and reduce contact resistance.

Due to the temperature gradient in the samples, some will have a tendency to bow during test.

Surrounding the lower heat sink are barrier terminal strips to which power and thermocouple leads are attached. Section 3 of this manual describes the arrangements of these therminals.

The standard (conventional) stack consists from the bottom up, the lower heat sink, the lower sample, the main and guard heater assembly, the top sample and the top heat sink. In its simplest form, the GP-500 may be operated in this manner.

A cylindrical shroud is provided which may be placed around the stack and filled with insulation. Operation close to room temperature does not require the use of this insulation although it is wise to put the shroud in place to protect the stack and its wiring. At temperatures much above room temperature , the shroud should be filled with insulation to ease the guard heater load and provide a more isothermal environment.

There are basically two controls used for operating the guarded hot-plate. The main heater is supplied electrical power from an adjustable regulated D-C power supply. The main and guard heater assembly contains a differential thermopile with junctions alternating between the two heater sections. The signal from this thermopile is fed into a zero-centered optical meter (API) located at the upper left of the control panel. The signal is then amplified in a control module and used to gate a pair of silicon controled rectifiers. The output of the SCR's is used to supply power to the guard heater. When the two heaters are balanced, a null signal is achieved.

All primary data is obtained by means of a precision millivolt potentiometer. Eight thermocouples are available for reading sample surface temperatures. There are therefore two available for each surface.

These may be used to duplicate surface temperature measurements in the main heater section or else one or two may be used to monitor the guard region to bias the guard heater control if required. The thermocouples are referenced to an automatic ice reference (J. Kaye).

Main heater current and voltage data is also obtained on the potentiometer through the use of a precision shunt and voltage divider located in the heater circuit.

A momentary switch is provided to read out the guard heater signal to monitor approach to balance during transient or cycle swing. These

switches are momentary since while they are being read, the heaters are not being controlled.

The controls and read out instrumentation are located in the control panel. The controls are all well labeled and are self explanatory. The use of these controls will be described further in Section 3 of this manual.

The enclosure cabinet has a rear door for easy access for occasional servicing. In addition, A service loop has been provided in the wiring, permitting the pivoting of the control panel at its base if access from the front is required. Depending on usage (and how frequently the operator forgets to shut off the potentiometer when not in use) the potentiometer batteries will require replacement. The batteries may be replaced by removing the top panel. Other than for this reason, once the instrument is operating well, all necessary controls are available externally.

2. INSTRUMENT INSTALLATION

The GP-500 will be shipped in a large crate consisting of a plywood base and top section. The top section is released by removing the eight screws along the base of the crate. The top section may then be removed and the instrument lifted from the base. Do not lift the instrument by the ends alone as it may buckle in the center.

The instrument should be installed in well lighted room (for ease in installing samples and small thermocouples). The instrument should be located to permit access to all four sides if possible although it is possible but not desirable to service it from the front and rear. It also is desirable to be able to work from the front and left side of the test section.

The power lines and water lines may be connected. A water flow of approximately 1.25 gpm is required. (See wiring diagram for power requirements). It is strongly recommended that permanent tubing or pipes be installed rather than hoses. <u>There should be no valve in the outlet line since full line pressure may cause a permanent bowing of the heat sinks.</u>

The potentiometer and optical meter contain wire shunts across the input therminals to prevent damage during shipment. These should be removed.

The power may then be turned on by depressing the main power and cooling water switches. When the water flow has started, press the reset push button. The main and guard heater circuits may then be operated by depressing their switches.

The main heater circuit has a 32 VDC maximum output and may be read on the potentiometer. Care should be taken never to short the guard heater circuit to ground as this would overload the silicone controlled rectifiers and cause them to fail.

After approximately 15 minutes the reference junction light should begin to cycle indicating the ice point has been reached.

The heater assemblies, upper heat sink, stack insulation and other accessory components are shipped in separate containers and should be unpacked and examined. Care should be taken to protect the finished surfaces of the heat sinks and heaters.

3. OPERATING AND TEST PROCEDURE

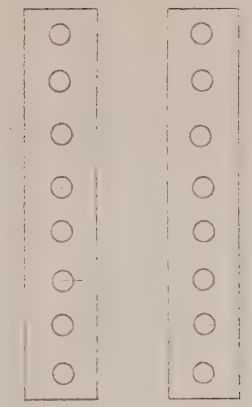
The guarded hot-plate thermal conductivity instrument is quite simple to operate especially for an individual who has had some experience in a thermophysical experimental laboratory. Even a man without experience, if given a reasonable initial amount of supervision usually becomes quite skilled after several tests with the guarded hot-plate. It should be emphasized however that good data is not automatic, and careful test section assembly and operation is required to obtain the quoted accuracy for this instrument.

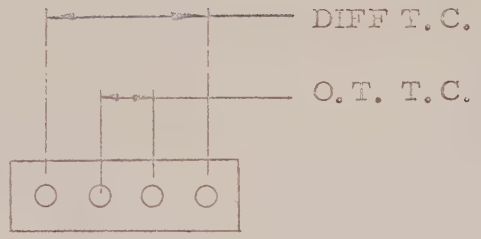
Perhaps the most critical phase of operation of the instrument is the assembly of the test section. The material to be tested should be well characterized (source, history, appearance, chemical and other physical properties) before running a test. A good deal of the scatter in published data results, not from the instrument or method but from a true variation between sample materials. The surfaces should be flat and have a fairly good finish to minimize and provide a uniform contact resistance. The samples dimensions should be obtained, taking the thickness at several locations.

To assemble the stack, the instrumented lower sample is installed on the lower heat sink followed by the installation of the main and guard heater assembly. It is wise to attach the various heater power and thermocouple leads as the stack is assembled. The circuits may then be checked during assembly to avoid having to dissassemble the full stack, should a bottom thermocouple become discontinuous.

The following figure shows the location of the various terminals and the heater leads are tagged to correspond. Care should be exercised to avoid shorting wires together or to the structure (ground). A shorted guard heater lead will overload the silicone controlled rectifiers

THERMAL CONDUCTIVITY INSTRUMENT
BASE PLATE BARRIER STRIPS





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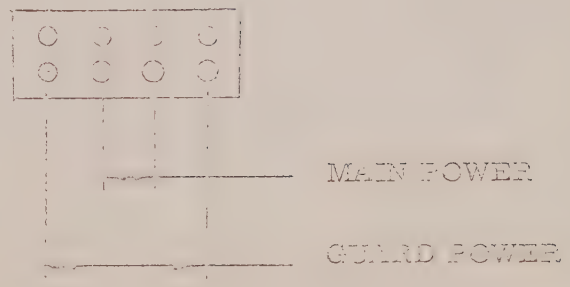
— CONSTANTAN, RED



supplying that circuit. The thermocouple barrier strips are single screw type. This is intentional, to force the contact of the thermocouple wire with the extension wire, thereby avoiding the introduction of a dissimilar material.

The sheathed hoses from the top heat sink may then be connected to the quick connections at the rear of the stack.

After all circuits have been checked, the shroud may be placed around the stack and the insulation added.

To operate the instrument the main power and cooling water switches are depressed and the reset push button is pressed momentarily. The lighted cooling water switch will indicate that the power is on. Should it fail to stay on, it will be because the water flow is insufficient.

The reference junction light will turn on with the main power and will cycle after 15 minutes or so indicating the ice reference has been achieved.

The main heater power may be turned on and adjusted to the desirable voltage. This is indicated by setting the rotary selector switch on position #9 and reading. The conversion is 1 mv is equal to 1 volt across the heater. (See the enclosed manual describing the use of the potentiometer.) The current may be read in the same manner in position # 10 on the rotary selector switch (10 mv per amp). (Note: Depress slightly and release the potentiometer e m f switch and adjust depending on the unbalance until balance is achieved - do not hold the button depressed with the e m f off scale).

The guard heater may be turned on and allowed to balance with the main heater. Both heaters should be allowed to equilibrate together. The control signal to the guard heater may be read by placing the rotary selector switch in position # 11 and switching the momentary toggle switch to "Read" position. It must be held while the potentiometer is balanced. Release this switch as soon as possible since the heater is not controlled correctly while in this position. Should the guard heater balance with a slight off-set either + or -, it may be corrected by removing the chrome-plated cap beneath the zero-centered optical meter (API) and adjusting the screw or by adjusting the knob immediately below the controller.

Should the guard heater swing or cycle at a greater value then desired, it may be damped by adjusting the small potentiometer in in series with the differential thermopile (located inside the cabinet).

Once the heaters are balanced at the desired temperature level, the voltage, current and all thermocouples are read and recorded. With a guarded hot-plate it is an absolute necessity that equilibrium be achieved. It is recommended that the ASTM Specifications be followed, that is, observations be made at intervals of not greater than 1 hour over a period of 5 hours during which the measured thermal conductivity does not vary more than 1%. Thermal conductivity measurements are by nature time consuming and any attempt to speed them usually is at a sacrifice of accuracy.

It is recommended that the instrument be operated with approximately 50° F across the sample. If the gradient is much smaller than this, temperature measurements might effect the overall accuracy. If the temperature drop is much in excess of 100° F, excessive sample bowing may occur.

Determinations at higher temperatures are best performed by inserting a thermal resistance such as a sheet of silicone rubber, mica mat or ceramic slab between the sample cold face and the heat sink.

The installation of thermocouples requires special attention. There are many methods, some of which depend on the type of material being tested and some of which depend on personnel preference. There are commercial thermocouples available but in general these are expensive and we find not the best suited for thermal conductivity measurements. In general it is best to use the minimum sized wire compatible with the intended test. It is recommended that premium grade wire be used and all thermocouples used in a single test be made from the same spools. Thermo-Physics provides one set of thermocouples (8) with the instrument.

Usually bare wire is used although small diameter insulated wire may be used. Barrier strip locations permit either across the stack installation or an arrangement with both leads coming out on the same side. With bare wire, the wire must be insulated from the heat sinks and heater assemblies although the junction itself may be touching to the structure. With plastic samples a small groove may be provided in the sample face to allow for the wire. With rubber or fiber samples, deflection of the sample is usually sufficient to allow for the wire diameter. Sheets of mylar, silicone rubber, teflon, Dupont H film or mica may be used to insulate the wire from the heat sinks. With electrically conducting samples, the wires must be insulated from the sample itself. This may be accomplished again by the use of the above insulating materials or with ceramic tubes which may be laid in sample grooves. It is important that

the junction measures the face temperature of the sample. This is best done by cementing or otherwise physically contacting junction to surface.

It is recommended that below 450° F with solid samples, a thin layer of heat conductive grease such as Dow Corning 340 be applied to the stack interfaces or at least at the thermocouple junction to minimize and make uniform the contact resistance.

4. DATA REDUCTION

The thermocouple e m f signals are converted to temperatures (see Section 5) and from these the temperature differences across the samples are determined. Usually the differences are averaged as are the sample thickness as measured prior to the test. The voltage and current measurements are multiplied to produce the wattage dissipation from the main heater. This in turn is divided by 2 to establish the average heat flow through a single sample. Finally the thermal conductivity is determined from Fourier's equation in the following form:

$$k = \frac{Q \quad \Delta x}{A \quad \Delta T}$$

where

k	=	thermal conductivity, Watts/cm - °C (BTU/hr-ft-°F)
Q	=	1/2 main heater power, Watts (BTU/hr)
A	=	main heater area (one side), cm^2 (ft^2)
Δx	=	average sample thickness, cm (ft)
ΔT	=	average temperature difference across sample, °C (°F)

The thermal conductivity value is usually reported at an arithmatic mean sample temperature obtained by averaging the four surface temperatures.

5. COPPER CONSTANTAN TEMPERATURE CONVERSION TABLE

Table 20. Copper-Constantan Thermocouples

(Electromotive Force in Absolute Millivolts. Temperatures in Degrees F.* Reference Junctions at 32° F.)

Millivolts	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	Millivolts
	Degrees F											
−5.00	−272.4	−281.8	−291.5	−301.7	−312.3							−5.00
−4.00	−192.0	−199.2	−206.6	−214.1	−221.8	−229.7	−237.8	−246.0	−254.5	−263.3	−272.4	−4.00
−3.00	−126.2	−132.4	−138.6	−144.9	−151.3	−157.8	−164.4	−171.1	−178.0	−184.9	−192.0	−3.00
−2.00	−68.6	−74.1	−79.6	−85.2	−90.9	−96.6	−102.4	−108.2	−114.2	−120.2	−126.2	−2.00
−1.00	−16.4	−21.4	−26.5	−31.6	−36.7	−41.9	−47.2	−52.4	−57.8	−63.2	−68.6	−1.00
(−) 0.00	32.0	27.3	22.6	17.8	13.0	8.2	3.4	−1.5	−6.4	−11.4	−16.4	(−) 0.00
(+) 0.00	32.0	36.7	41.3	45.9	50.5	55.0	59.6	64.1	68.6	73.0	77.5	(+) 0.00
1.00	77.5	81.9	86.2	90.6	95.0	99.3	103.6	107.8	112.1	116.3	120.5	1.00
2.00	120.5	124.7	128.9	133.1	137.3	141.4	145.4	149.5	153.6	157.7	161.7	2.00
3.00	161.7	165.7	169.7	173.7	177.7	181.7	185.6	189.5	193.5	197.4	201.3	3.00
4.00	201.3	205.2	209.0	212.9	216.7	220.5	224.4	228.2	232.0	235.7	239.5	4.00
5.00	239.5	243.2	247.0	250.7	254.4	258.1	261.9	265.6	269.2	272.9	276.6	5.00
6.00	276.6	280.2	283.9	287.5	291.1	294.7	298.3	301.9	305.5	309.1	312.6	6.00
7.00	312.6	316.2	319.7	323.3	326.8	330.3	333.8	337.3	340.8	344.3	347.8	7.00
8.00	347.8	351.3	354.8	358.2	361.7	365.1	368.6	372.0	375.4	378.8	382.2	8.00
9.00	382.2	385.6	389.0	392.4	395.8	399.2	402.5	405.9	409.2	412.6	415.9	9.00
10.00	415.9	419.2	422.6	425.9	429.2	432.5	435.9	439.2	442.4	445.7	449.0	10.00
11.00	449.0	452.3	455.5	458.8	462.1	465.3	468.6	471.9	475.1	478.3	481.5	11.00
12.00	481.5	484.7	488.0	491.2	494.4	497.6	500.8	504.0	507.2	510.4	513.5	12.00
13.00	513.5	516.7	519.9	523.1	526.2	529.4	532.5	535.7	538.8	542.0	545.1	13.00
14.00	545.1	548.2	551.3	554.5	557.6	560.7	563.8	566.9	570.0	573.1	576.2	14.00
15.00	576.2	579.3	582.4	585.5	588.6	591.6	594.7	597.8	600.8	603.9	606.9	15.00
16.00	606.9	610.0	613.0	616.1	619.1	622.2	625.2	628.2	631.3	634.3	637.3	16.00
17.00	637.3	640.3	643.3	646.4	649.4	652.4	655.4	658.4	661.4	664.4	667.4	17.00
18.00	667.4	670.3	673.3	676.3	679.3	682.2	685.2	688.2	691.1	694.1	697.1	18.00
19.00	697.1	700.0	703.0	705.9	708.9	711.8	714.8	717.7	720.6	723.6	726.5	19.00
20.00	726.5	729.4	732.3	735.3	738.2	741.1	744.0	746.9	749.9			20.00
Millivolts	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	Millivolts

*Based on the International Temperature Scale of 1948.

Table 21. Copper-Constantan Thermocouples

(Electromotive Force in Absolute Millivolts. Temperature in Degrees F.* Reference Junctions at 32° F.)

°F	0	1	2	3	4	5	6	7	8	9	10	°F
	Millivolts											
−310	−5.379	−5.388	−5.397	−5.406	-------	-------	-------	-------	-------	-------	-------	−310
−300	−5.284	−5.294	−5.303	−5.313	−5.322	−5.332	−5.341	−5.351	−5.360	−5.370	−5.379	−300
−290	−5.185	−5.195	−5.205	−5.215	−5.225	−5.235	−5.245	−5.254	−5.264	−5.274	−5.284	−290
−280	−5.081	−5.092	−5.102	−5.113	−5.124	−5.134	−5.144	−5.154	−5.165	−5.175	−5.185	−280
−270	−4.974	−4.985	−4.996	−5.007	−5.018	−5.029	−5.039	−5.050	−5.060	−5.071	−5.081	−270
−260	−4.863	−4.874	−4.885	−4.897	−4.908	−4.919	−4.930	−4.941	−4.952	−4.963	−4.974	−260
−250	−4.747	−4.759	−4.770	−4.782	−4.794	−4.805	−4.817	−4.829	−4.840	−4.851	−4.863	−250
−240	−4.627	−4.640	−4.652	−4.664	−4.676	−4.688	−4.700	−4.712	−4.724	−4.735	−4.747	−240
−230	−4.504	−4.517	−4.529	−4.542	−4.554	−4.566	−4.579	−4.591	−4.603	−4.615	−4.627	−230
−220	−4.377	−4.390	−4.403	−4.415	−4.428	−4.441	−4.454	−4.466	−4.479	−4.492	−4.504	−220
−210	−4.246	−4.259	−4.272	−4.286	−4.299	−4.312	−4.325	−4.338	−4.351	−4.364	−4.377	−210
−200	−4.111	−4.125	−4.138	−4.151	−4.165	−4.179	−4.192	−4.206	−4.219	−4.232	−4.246	−200
−190	−3.972	−3.986	−4.000	−4.014	−4.028	−4.042	−4.056	−4.069	−4.083	−4.097	−4.111	−190
−180	−3.829	−3.844	−3.858	−3.873	−3.887	−3.901	−3.915	−3.929	−3.944	−3.958	−3.972	−180
−170	−3.684	−3.698	−3.713	−3.727	−3.742	−3.757	−3.771	−3.786	−3.800	−3.815	−3.829	−170
−160	−3.533	−3.548	−3.564	−3.579	−3.594	−3.609	−3.624	−3.639	−3.654	−3.669	−3.684	−160
−150	−3.380	−3.396	−3.411	−3.426	−3.441	−3.457	−3.472	−3.488	−3.503	−3.518	−3.533	−150
−140	−3.223	−3.238	−3.254	−3.270	−3.286	−3.301	−3.317	−3.333	−3.349	−3.365	−3.380	−140
−130	−3.062	−3.078	−3.094	−3.110	−3.127	−3.143	−3.159	−3.175	−3.191	−3.207	−3.223	−130
−120	−2.897	−2.914	−2.931	−2.947	−2.964	−2.980	−2.997	−3.013	−3.030	−3.046	−3.062	−120
−110	−2.730	−2.747	−2.764	−2.781	−2.797	−2.814	−2.831	−2.847	−2.864	−2.881	−2.897	−110
−100	−2.559	−2.577	−2.594	−2.611	−2.628	−2.645	−2.662	−2.679	−2.696	−2.713	−2.730	−100
−90	−2.385	−2.402	−2.420	−2.437	−2.455	−2.472	−2.490	−2.507	−2.525	−2.542	−2.559	−90
−80	−2.207	−2.225	−2.243	−2.260	−2.278	−2.296	−2.314	−2.332	−2.349	−2.367	−2.385	−80
−70	−2.026	−2.044	−2.063	−2.081	−2.099	−2.117	−2.135	−2.153	−2.171	−2.189	−2.207	−70
−60	−1.842	−1.860	−1.879	−1.897	−1.916	−1.934	−1.953	−1.971	−1.989	−2.008	−2.026	−60
−50	−1.654	−1.673	−1.692	−1.711	−1.729	−1.748	−1.767	−1.786	−1.804	−1.823	−1.842	−50
−40	−1.463	−1.482	−1.502	−1.521	−1.540	−1.559	−1.578	−1.597	−1.616	−1.635	−1.654	−40
−30	−1.270	−1.289	−1.308	−1.328	−1.347	−1.367	−1.386	−1.406	−1.425	−1.444	−1.463	−30
−20	−1.072	−1.092	−1.112	−1.132	−1.152	−1.171	−1.191	−1.210	−1.230	−1.250	−1.270	−20
−10	−0.872	−0.893	−0.913	−0.933	−0.953	−0.973	−0.993	−1.013	−1.033	−1.053	−1.072	−10
(−)0	−0.670	−0.690	−0.710	−0.730	−0.751	−0.771	−0.792	−0.812	−0.832	−0.852	−0.872	(−)0
°F	0	1	2	3	4	5	6	7	8	9	10	°F

*Based on the International Temperature Scale of 1948.

Table 21. Copper Constantan Thermocouples—Con.

(Electromotive Force in Absolute Millivolts. Temperatures in Degrees F.* Reference Junctions at 32° F.)

°F	0	1	2	3	4	5	6	7	8	9	10	°F
	Millivolts											
(+)0	−0. 670	−0. 649	−0. 629	−0. 608	−0. 588	−0. 567	−0. 546	−0. 526	−0. 505	−0. 484	−0. 463	(+)0
10	−0. 463	−0. 442	−0. 421	−0. 401	−0. 380	−0. 359	−0. 339	−0. 318	−0. 297	−0. 275	−0. 254	10
20	−0. 254	−0. 233	−0. 212	−0. 191	−0. 170	−0. 149	−0. 128	−0. 107	−0. 085	−0. 064	−0. 042	20
30	−0. 042	−0. 021	0. 000	0. 021	0. 042	0. 064	0. 086	0. 107	0. 129	0. 150	0. 171	30
40	0. 171	0. 193	0. 215	0. 236	0. 258	0. 280	0. 302	0. 324	0. 346	0. 367	0. 389	40
50	0. 389	0. 411	0. 433	0. 455	0. 477	0. 499	0. 521	0. 543	0. 565	0. 587	0. 609	50
60	0. 609	0. 631	0. 654	0. 676	0. 698	0. 720	0. 743	0. 765	0. 787	0. 809	0. 832	60
70	0. 832	0. 854	0. 877	0. 899	0. 922	0. 944	0. 967	0. 990	1. 012	1. 035	1. 057	70
80	1. 057	1. 080	1. 103	1. 126	1. 148	1. 171	1. 194	1. 217	1. 240	1. 263	1. 286	80
90	1. 286	1. 309	1. 332	1. 355	1. 378	1. 401	1. 424	1. 448	1. 471	1. 494	1. 517	90
100	1. 517	1. 540	1. 563	1. 587	1. 610	1. 633	1. 657	1. 680	1. 704	1. 727	1. 751	100
110	1. 751	1. 774	1. 798	1. 821	1. 845	1. 869	1. 893	1. 916	1. 940	1. 963	1. 987	110
120	1. 987	2. 011	2. 035	2. 059	2. 083	2. 107	2. 131	2. 154	2. 178	2. 202	2. 226	120
130	2. 226	2. 250	2. 274	2. 298	2. 322	2. 346	2. 370	2. 394	2. 418	2. 443	2. 467	130
140	2. 467	2. 491	2. 516	2. 540	2. 565	2. 589	2. 614	2. 638	2. 663	2. 687	2. 711	140
150	2. 711	2. 736	2. 760	2. 785	2. 810	2. 835	2. 859	2. 884	2. 908	2. 933	2. 958	150
160	2. 958	2. 982	3. 007	3. 032	3. 057	3. 082	3. 107	3. 132	3. 157	3. 182	3. 207	160
170	3. 207	3. 232	3. 257	3. 282	3. 307	3. 332	3. 357	3. 382	3. 407	3. 433	3. 458	170
180	3. 458	3. 483	3. 508	3. 534	3. 559	3. 584	3. 610	3. 635	3. 661	3. 686	3. 712	180
190	3. 712	3. 737	3. 762	3. 787	3. 813	3. 839	3. 864	3. 890	3. 915	3. 941	3. 967	190
200	3. 967	3. 993	4. 018	4. 044	4. 070	4. 096	4. 122	4. 148	4. 174	4. 199	4. 225	200
210	4. 225	4. 251	4. 277	4. 303	4. 329	4. 355	4. 381	4. 408	4. 434	4. 460	4. 486	210
220	4. 486	4. 512	4. 538	4. 564	4. 590	4. 617	4. 643	4. 670	4. 696	4. 722	4. 749	220
230	4. 749	4. 775	4. 801	4. 827	4. 854	4. 880	4. 907	4. 934	4. 960	4. 987	5. 014	230
240	5. 014	5. 040	5. 067	5. 094	5. 120	5. 147	5. 174	5. 200	5. 227	5. 254	5. 280	240
250	5. 280	5. 307	5. 334	5. 361	5. 388	5. 415	5. 442	5. 469	5. 496	5. 523	5. 550	250
260	5. 550	5. 577	5. 604	5. 631	5. 658	5. 685	5. 712	5. 739	5. 766	5. 794	5. 821	260
270	5. 821	5. 848	5. 875	5. 903	5. 930	5. 957	5. 985	6. 012	6. 040	6. 067	6. 094	270
280	6. 094	6. 122	6. 149	6. 177	6. 204	6. 232	6. 259	6. 287	6. 314	6. 342	6. 370	280
290	6. 370	6. 397	6. 425	6. 453	6. 481	6. 508	6. 536	6. 564	6. 592	6. 620	6. 647	290
300	6. 647	6. 675	6. 703	6. 731	6. 759	6. 786	6. 814	6. 842	6. 870	6. 898	6. 926	300
310	6. 926	6. 954	6. 982	7. 010	7. 038	7. 066	7. 095	7. 123	7. 151	7. 180	7. 208	310
320	7. 208	7. 236	7. 264	7. 292	7. 321	7. 349	7. 377	7. 405	7. 434	7. 462	7. 491	320
330	7. 491	7. 519	7. 548	7. 576	7. 605	7. 633	7. 661	7. 690	7. 719	7. 747	7. 776	330
340	7. 776	7. 805	7. 834	7. 862	7. 891	7. 920	7. 949	7. 978	8. 006	8. 035	8. 064	340
350	8. 064	8. 092	8. 120	8. 149	8. 178	8. 207	8. 236	8. 265	8. 294	8. 323	8. 352	350
360	8. 352	8. 381	8. 410	8. 439	8. 468	8. 497	8. 526	8. 555	8. 584	8. 613	8. 642	360
370	8. 642	8. 672	8. 701	8. 730	8. 759	8. 788	8. 818	8. 847	8. 876	8. 905	8. 935	370
380	8. 935	8. 964	8. 994	9. 023	9. 052	9. 082	9. 111	9. 141	9. 170	9. 200	9. 229	380
390	9. 229	9. 259	9. 288	9. 317	9. 347	9. 376	9. 406	9. 436	9. 466	9. 495	9. 525	390
400	9. 525	9. 555	9. 584	9. 614	9. 644	9. 674	9. 703	9. 733	9. 763	9. 793	9. 823	400
°F	0	1	2	3	4	5	6	7	8	9	10	°F

*Based on the International Temperature Scale of 1948.

Table 21. Copper-Constantan Thermocouples—Con.

(Electromotive Force in Absolute Millivolts. Temperatures in Degrees F.* Reference Junctions at 32° F.)

°F	0	1	2	3	4	5	6	7	8	9	10	°F
	Millivolts											
400	9. 525	9. 555	9. 584	9. 614	9. 644	9. 674	9. 703	9. 733	9. 763	9. 793	9. 823	400
410	9. 823	9. 853	9. 883	9. 913	9. 943	9. 973	10. 003	10. 033	10. 063	10. 093	10. 123	410
420	10. 123	10. 153	10. 183	10. 213	10. 243	10. 273	10. 303	10. 333	10. 363	10. 393	10. 423	420
430	10. 423	10. 453	10. 483	10. 514	10. 544	10. 574	10. 604	10. 635	10. 665	10. 695	10. 726	430
440	10. 726	10. 756	10. 787	10. 817	10. 848	10. 878	10. 909	10. 939	10. 969	11. 000	11. 030	440
450	11. 030	11. 061	11. 091	11. 122	11. 152	11. 183	11. 214	11. 244	11. 275	11. 305	11. 336	450
460	11. 336	11. 366	11. 397	11. 428	11. 459	11. 490	11. 520	11. 551	11. 581	11. 612	11. 643	460
470	11. 643	11. 674	11. 704	11. 735	11. 766	11. 797	11. 828	11. 859	11. 891	11. 922	11. 953	470
480	11. 953	11. 984	12. 015	12. 046	12. 077	12. 108	12. 138	12. 170	12. 201	12. 232	12. 263	480
490	12. 263	12. 294	12. 325	12. 356	12. 387	12. 418	12. 450	12. 481	12. 512	12. 543	12. 575	490
500	12. 575	12. 606	12. 637	12. 669	12. 700	12. 732	12. 763	12. 794	12. 825	12. 857	12. 888	500
510	12. 888	12. 919	12. 951	12. 983	13. 014	13. 046	13. 077	13. 108	13. 140	13. 172	13. 203	510
520	13. 203	13. 235	13. 267	13. 298	13. 330	13. 362	13. 393	13. 425	13. 457	13. 488	13. 520	520
530	13. 520	13. 552	13. 583	13. 615	13. 647	13. 678	13. 710	13. 742	13. 774	13. 806	13. 838	530
540	13. 838	13. 869	13. 901	13. 933	13. 965	13. 997	14. 029	14. 061	14. 093	14. 125	14. 157	540
550	14. 157	14. 189	14. 221	14. 253	14. 285	14. 317	14. 349	14. 381	14. 413	14. 445	14. 477	550
560	14. 477	14. 509	14. 541	14. 573	14. 605	14. 637	14. 670	14. 702	14. 734	14. 766	14. 799	560
570	14. 799	14. 831	14. 864	14. 896	14. 928	14. 961	14. 993	15. 025	15. 057	15. 090	15. 122	570
580	15. 122	15. 155	15. 187	15. 219	15. 252	15. 284	15. 317	15. 349	15. 382	15. 414	15. 447	580
590	15. 447	15. 480	15. 512	15. 545	15. 577	15. 610	15. 642	15. 675	15. 707	15. 740	15. 773	590
600	15. 773	15. 806	15. 838	15. 871	15. 904	15. 937	15. 969	16. 002	16. 035	16. 068	16. 101	600
610	16. 101	16. 133	16. 166	16. 199	16. 232	16. 264	16. 297	16. 330	16. 363	16. 396	16. 429	610
620	16. 429	16. 462	16. 495	16. 528	16. 560	16. 593	16. 626	16. 659	16. 692	16. 725	16. 758	620
630	16. 758	16. 791	16. 824	16. 857	16. 890	16. 924	16. 957	16. 990	17. 023	17. 056	17. 089	630
640	17. 089	17. 122	17. 155	17. 189	17. 222	17. 255	17. 288	17. 321	17. 354	17. 388	17. 421	640
650	17. 421	17. 454	17. 488	17. 521	17. 554	17. 588	17. 621	17. 654	17. 688	17. 721	17. 754	650
660	17. 754	17. 788	17. 821	17. 854	17. 888	17. 921	17. 955	17. 988	18. 022	18. 055	18. 089	660
670	18. 089	18. 123	18. 156	18. 190	18. 223	18. 257	18. 290	18. 324	18. 357	18. 391	18. 425	670
680	18. 425	18. 458	18. 492	18. 526	18. 560	18. 593	18. 627	18. 660	18. 694	18. 727	18. 761	680
690	18. 761	18. 795	18. 829	18. 863	18. 896	18. 930	18. 964	18. 998	19. 032	19. 066	19. 100	690
700	19. 100	19. 134	19. 168	19. 201	19. 235	19. 269	19. 303	19. 337	19. 371	19. 405	19. 439	700
710	19. 439	19. 473	19. 506	19. 540	19. 574	19. 608	19. 642	19. 676	19. 711	19. 745	19. 779	710
720	19. 779	19. 813	19. 847	19. 881	19. 915	19. 949	19. 983	20. 018	20. 052	20. 086	20. 120	720
730	20. 120	20. 154	20. 188	20. 223	20. 257	20. 291	20. 325	20. 359	20. 394	20. 428	20. 463	730
740	20. 463	20. 497	20. 531	20. 565	20. 599	20. 634	20. 668	20. 702	20. 736	20. 771	20. 805	740
750	20. 805	20. 840	20. 874	-------	-------	-------	-------	-------	-------	-------	-------	750
°F	0	1	2	3	4	5	6	7	8	9	10	°F

*Based on the International Temperature Scale of 1948.

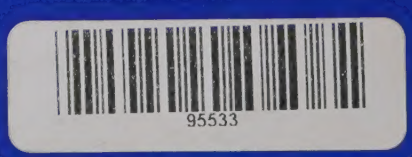
6. PARTS LIST

See Parts List Call out on Wiring Diagram for Commercial Parts.

Thermo-Physics Fabricated Parts

Part No.	Qty.	Description
GP-500-1	2	Heat Sink Assembly
GP-500-2	2	Heat Sink Insulator
GP-500-3	1	Heat Sink Support
GP-500-4	1	Base Plate
GP-500-5	3	Tie Rod
GP-500-6	1	Shroud
GP-500-7	1	Main Heater Assembly

Cabinet Parts, plumbing, wiring brackets and small hardware are not assigned numbers. Please refer to these parts by description.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